NORTHEAST REGIONAL RESEARCH PUBLICATION

Drought Frequency in the Northeastern United States

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The Authors

W. H. Dickerson is Agricultural Engineer in the West Virginia University Agricultural Experiment Station; B. E. Dethier is Professor of Meteorology, New York State College of Agriculture, Cornell University.

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COLLEGE OF AGRICULTURE AND FORESTRY
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Technical Committee of Northeastern Regional Research Project NE-35, "Climate of the Northeast – Analysis and Relationship to Plant Response"

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C ntents

Summary

Studies by Fieldhouse and Palmer (4) have established that the Northeastern United States, a humid region, has been subjected to numerous droughts in the past 40 years. The Drought Index developed by Palmer (8) provides a measure of drought severity and duration. Employing this concept the frequency, expressed as a return period or recurrence interval, for drought severity was determined for the Northeast.

In terms of frequency, the general expectancy is for moderate drought (-2.00 to -2.99) once in five years, severe (-3.00 to -3.99) once in ten years, and a severity of -5.00 to -7.00 once in 50 years. The stated values of the Index are expected on the average to be equalled or exceeded once in the periods given and no periodicity is implied. While these expectancies generally apply to the Northeast there is significant variation within the region.

Areas of least drought severity include the mountainous parts of southwestern Virginia and the western Carolinas, some coastal areas of the Carolinas, part of New York adjacent to the Great Lakes and all of New England east of the Connecticut Valley. Areas of worst severity include the Hudson Valley, the Del-Mar-Va Peninsula, eastern Maryland, northern Virginia, northern West Virginia along with some climatic divisions in southwestern Pennsylvania and eastern Ohio. With the exception of the coincidence of low severity with the high rainfall areas of the mountains of Virginia and the Carolinas there is no striking relationship between drought patterns and topography or meteorological characteristics of the Northeast.

rought Frequency in the lortheastern United States

W. H. DICKERSON AND B. E. DETHIER

T HE VARIABILITY of precipitation is a characteristic of the climate of the Northeast as well as most other humid areas. It is not unusual for areas of emingly abundant precipitation to suffer a soil moisture shortage that affects ricultural production and the deficit of precipitation not infrequently persists the point where groundwater levels and stream flow are adversely influenced. describe these situations numerous definitions of drought have been oposed but none has received general or widespread acceptance. A few amples of the many that may be found in the literature, Hoyt (6), Havens (5), rr (1) and Fieldhouse and Palmer (4), serve to illustrate the lack of agreement d, in some cases subjectivity, involved in establishing the existence of drought. is nevertheless an inescapable fact that drought is a troublesome and costly iture of the climate of the Northeastern region of the United States as well as ier humid regions of the world. Reference (9) contains papers on aspects of drought of the 1960's in the Northeast.

fects on Agriculture, Municipalities and Industry

An agricultural drought is experienced when rainfall is inadequate to intain soil moisture at optimum levels in terms of the normal or generally erienced moisture supply for the region in question. Thus the meaning of quate soil moisture is relative. However, crop production is related to plant s cies, soil fertility, and other environmental factors in addition to soil isture. Lack of available soil moisture for crop production is generally the f t manifestation of a precipitation deficit, therefore agriculture is particularly s sitive to drought. Indeed, a period of only 10 to 14 days without rain may stically curtail germination of seeds or the growth or maturation of some c ps on some soils. The more shallow rooted the crop and the smaller the a ilable water holding capacity of the soil the greater is the vulnerability to ught.

A meteorological drought may be described, e.g., Carr (1), as a significant rease from normal precipitation over a wide area and for an extended time. situation is more severe and widespread than the local or short-term ation in rainfall that can create an agricultural drought. Hydrologic drought

is still more widespread and severe, usually lasting one or more years. It typified by the drying up of springs and small streams, falling water level i wells, the shrinking of rivers, and the depletion of water stored in lakes an reservoirs. Yevjevich (9) has proposed criteria for objective definitions (hydrologic droughts.

A drought may exist for the agriculturalist before it is evident in tl meterological or hydrological sense. Conversely an agricultural drought may b ended, at least temporarily, by rainfall that replenishes the available so mositure supply but does not add to groundwater or appear as stream flow. A agricultural drought may exist sporadically because of poor distribution rainfall when the total precipitation for the year is near normal or above and r meterological or hydrological drought would be evident. If an agricultur drought may exist without serious consequences for municipal and industri interests, it is likewise true that the latter may run low on water whi agriculture does not suffer. This can happen when rainfall is so fortuitous distributed as to keep the available soil moisture for crops in a reasonab balance with the demands of evapotranspiration but such precipitation episod may provide little or no excess moisture for the replenishment of groundwat or contribution to surface runoff. Agriculture needs water mostly during t warm or growing season. In contrast to this, municipal and industrial wat supplies undergo withdrawal on a year-around basis with little seasor diminution in requirements.

As these definitions and concepts imply, drought is harmful and costly many segments of the economy but the most directly affected are agricultu and municipal and industrial users of water. Agriculturists are primar concerned because of the importance of soil moisture in crop productio Engineers and hydrologists are interested in drought because of its effect up water quality, streamflow, waste removal, and ground water levels.

Causes of Drought

Many theories have been advanced to explain the onset and persistence drought. Some of the current ideas received with the most credence suggest tl changes in the rainfall regime may be due to colder than usual temperature the oceans around North America, changes in the large-scale circulation of t air resulting in a shift of prevailing wind patterns, low sunspot activity, changes in the climate caused by dust thrown into the atmosphere by volca eruptions. An underlying concept common to most theories is that variation the energy from the sun are directly or indirectly responsible for changes in climate.

Synoptic patterns accompanying the drought of the 1960's in the Northeast dicate a slowdown or failure in the flow of moisture laden air from the Gulf of exico or the Atlantic Ocean, a change in the movement of frontal systems ross the region, or the failure of coastal storms to follow a tract that brings oisture into the area. Also, there was a greater frequency of anticyclones oving across the Northeastern United States during the warm months. The ore frequent invasions of cool dry air interfered with the normal flow of moist opical air from the Gulf of Mexico.

edicting Drought

Due to the complexity of the atmospheric circulation long-range forecasts ve lacked the accuracy necessary for drought prediction. As a result, interest s long centered about the identification of cycles in the weather that could e a clue to the expected timing of occurrence, severity and length of drought riods. Indeed, this aspect of the weather has been so fascinating that some 130 cles, Tannehill (10), have been proposed at one time or another for explaining e vagaries of the weather. One of the most well-known of these cycles is the uckner, attributable to the Viennese climatologist who proposed a 35-year cle. Another that has received much attention is the sunspot cycle which erages approximately 11 years but has been as short as 7 or as long as 17 years. mewhat along this same line, Tannehill explained how current weather netimes seems to duplicate previous weather development and cited examples how analogs have been used in forecasting. Of the many cycles which have en proposed, none offers a practical means of forecasting the beginning, erity or end of a drought period.

eather Modification

In relation to drought, interest in weather modification centers around two ergent concerns, namely, inadvertant modification, and a controlled or entifically induced modification for beneficial purposes. As an example of the st concern, it has been suggested that air pollution may be a factor tending to ng about unanticipated and uncontrolled changes in the climate. These may lude a shift in rainfall patterns, but the present understanding of the variables olved does not provide the basis for a satisfactory explanation or prediction the changes to be expected. In the past two decades, the interest in inmaking" has spread throughout the United States and indeed all over the rld. Based on ideas advanced by Drs. Langmuir, Schaefer, Vonnegut, and ers, developments in the late 1940's raised some hope that weather dification by cloud seeding could bring widespread relief from drought, rease precipitation over arid areas, eliminate lightning and hail as destructive

manifestations of local weather and hopefully modify or steer tropical hurricanes. A large number of carefully planned studies are now in progress on various aspects of weather modifications (11). The results to date suggest that relief from the vagaries of the weather through this means is not imminent, although holding out some hope of at least limited success for the future. The conclusion seems plain that protection from drought and augmentation of water supplies will have to be dependent on conventional methods for the immediate future.

Purpose of the Study

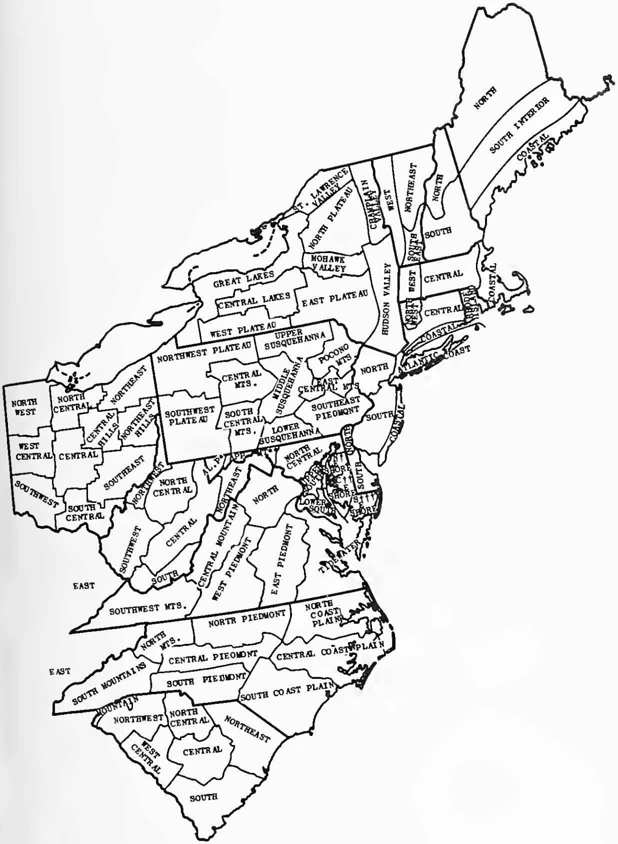
The work by Fieldhouse and Palmer (4) cited previously, indicates that the Northeast has always been subject to wet and dry spells. Commonly accepted means of alleviating the effects of drought include irrigation for agriculture and the storage of surface water in reservoirs and the drilling of more and deeper wells to tap groundwater for use by industry and for municipal consumption. These methods are expensive—so costly that the most careful scrutiny should be given to the various aspects of drought and the impact of drought on the water supply. As the demand for water increases, problems of evaluation, selection and development of supplies will necessarily become more complex.

Whenever man makes long-range plans that depend on the weather, he must depend on the climatological and hydrological data for the area. Present knowledge allows accurate weather forecasts for periods up to about five days, but this is generally too short to be of much use in decisions involving drought. A knowledge of drought occurrence in a region over past years will allow the estimation of the chances of occurrence in the future, a prerequisite in planning and designing for water supplies.

The Palmer Drought Index (8), which provides a measure of drought severity as well as duration, offered a unique opportunity to study drought frequency. The central purpose of the work reported herein has been to determine the frequency or return period associated with a given severity of drought. The return period is the average number of years within which a given event will be equalled or exceeded. No periodicity is implied in this use of the term.

The Data Sample

The data were obtained from the method of drought analysis developed by Palmer (8) and applied to the Northeastern United States by Fieldhouse and Palmer (4). The procedure derived monthly index values which are a measure of drought severity and identified the months affected. According to Fieldhouse and Palmer the procedure "treats drought severity as a function of accumulated



gure 1. Climatological divisions used in the Northeast regional drought analysis.

weighted differences between actual precipitation and the precipitation requi ment, where the requirement depends on the carryover of previous rainfall well as on the evapotranspiration, moisture recharge and runoff that would climatically appropriate for the particular time and place being investigat Thus, the average requirement is for normal rainfall, but individual periods m require much above or much below normal rainfall depending on the charac of the preceding weather and the temperature of the period question."

The method did not attempt to consider biological responses drought but concentrated on identification of various durations and severity drought periods by an analysis of the historical weather records. These recor were combined by climatic divisions so that the derived values apply to t geographical units delineated on the map of climatological divisions, (Figure Categories of drought severity are defined in Table 1.

Table 1. Classes of Dry Periods According to Palmer (8).

Drought Index	Description of Class
-0.50 -0.99	incipient drought
-1.00 to -1.99	mild drought
-2.00 to -2.99	moderate drought
-3.00 to -3.99	severe drought
≤ -4.00	extreme drought

The Palmer Drought Index assigned positive values to wet periods and negati values to dry periods.

Analytical Procedures

Each drought period was indentified by date of beginning and ending, the greatest severity index reached and by the duration in terms of consecut months affected. Severity data, representing climatic divisions, were compi into samples with the drought periods in chronological order. The data we arrayed in ascending order of severity with the data indentifications for periods retained. Data samples were then analyzed to obtain freque relationships.

In this procedure, a drought was indentified as existing when a specif index (≤ -0.50) was reached. Some years experienced no drought, others had or more. For this reason the data samples were considered to constitute a par series. The purpose of the study required establishment of a relations between the event (severity index) and a frequency or return period. The ret period was considered as the independent variable and the index the depend

tting positions were determined by the Weibull formula, Chow (2), which

$$F = \frac{M}{N+1}$$

= the cumulative frequency which may also be expressed as a return period in years,
= the order number of the event in an array,
= the number of years in the record.

For the purpose of analyzing the partial series the order number was ermined by assigning the lowest index (most extreme severity) order number , i.e., M = 1. This gives the event a return period of N + 1 years and responds to the method of handling an annual series when the Weibull tting equation is used.

The fitting procedure employed an exponential function in the form

$$y \ln b = \ln X - \ln a$$

This equation was reduced to a least squares fitting problem, using y as the ex (severity) on a linear scale and X the frequency (return period) on a rithmic scale (see Figure 2).

By graphical plots of the data and comparison of R^2 (coefficient of rmination) values to determine the percentage of the variability in the nt accounted for by the return period it was evident that this function erally provided a satisfactory fit to the data, with some exceptions noted r. The exponential function is supported as applying to partial series data by ley, Kohler and Paulhus (7) and by Chow (2). This model was subsequently l to determine the frequency relationships presented in Table 2.

ults of Frequency Analysis

Region Studied

Drought severity data were derived by climatic divisions for the area from ne to South Carolina and west to Ohio. Two climatic divisions were not uded, North Carolina, North Mountains (31-02) and South Carolina ntain (38-01) because they were not reported in the calculations by dhouse and Palmer (4).

The chief distinguishing physical feature of the area is the Appalachian ntains, running from Maine through the Carolinas. These mountains are lered on the east by lands which slope gently down to the sea and on the by more broken lands which slope away to lower elevations to the ward. The general precipitation pattern for the region has been described by

Dethier (3) as follows; "Most of the moisture for the region is transported fror the Gulf of Mexico and the Atlantic Ocean by the major storm systems in th atmosphere. Although these storms are the major year round producers c precipitation there are fewer during the summer season. Increased convecti activity over most of the area is more than adequate in compensating for th decrease in major storms. This results in a warm season precipitation maximu over the greater part of the region. The complex precipitation pattern is due, i part, to the rugged topography of the areas. Orographic lifting results i numerous centers of heavy precipitation over higher elevations and on th windward slopes. Areas of least precipitation are usually found in the lee or 'ra shadow' of the higher elevations.

The average annual precipitation ranges from 31 inches in extren northwestern New York to more than 52 inches at some of the higher elevatio in West Virginia, New York, Vermont and New Hampshire. . . The enti Atlantic seaboard area receives more than 44 inches per year as do sections the Adirondacks, central West Virginia, and northwestern Pennsylvania. Tl areas with lowest values include the rain shadows in Maryland, New Yor Pennsylvania and West Virginia."

Drought Severity

Tabulated values of the severity index for selected return periods are shov in Table 2, which also lists the greatest severity encountered for the peri analyzed (1929-1967). For all of the climatic divisions the one in two year ind value falls in the mild drought class (-1.00 to -1.99). With few exceptions t five-year expectancy is for a moderate drought category (-2.00 to -2.99) to equalled or exceeded. The ten-year index shows that severe drought (-3.00 -3.99) can be expected to occur within the span of a decade, on the average, most locations in the northeastern region as defined in this study. Generally t 50-year values of the index are between -5.00 and -7.00, and it may be not that these agree fairly closely with the extreme events observed although the are a few notable exceptions. For the most part the fitted line for the mod agrees well with the observed data. Figure 2 illustrates the relationship for t Central division (19-02) of Massachusetts.

Regional Patterns

Table 2 gives values of calculated severity indices for the Northeast climatic divisions, while Figure 3 was designed to show the enveloping curves the entire region. A question that arises naturally is, Do the climatic divisi values reported delineate a geographical pattern that may be related to topography, seasonal or annual rainfall, or other indentifiable meteorologi characteristics of the region? In examining this the calculated return per

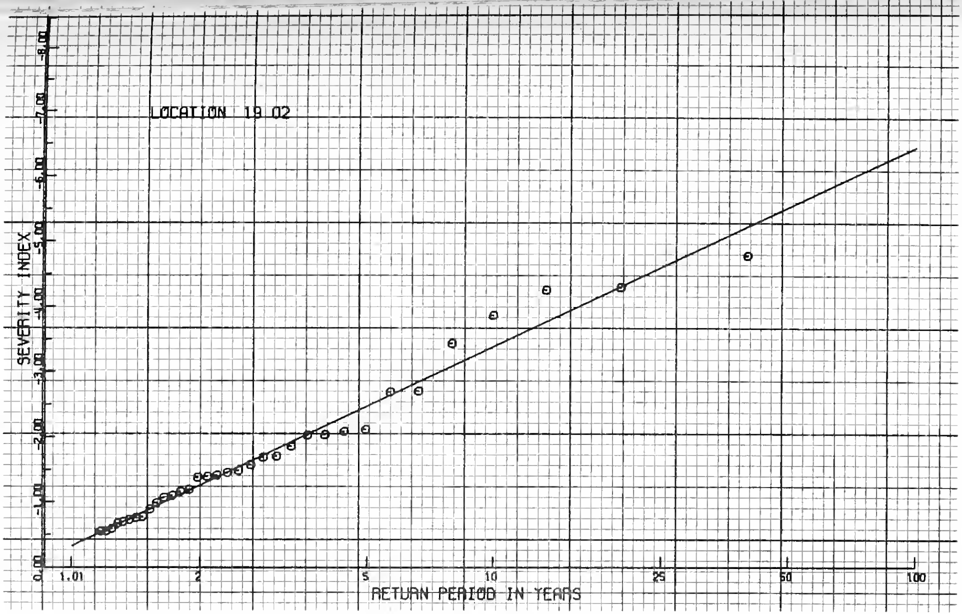
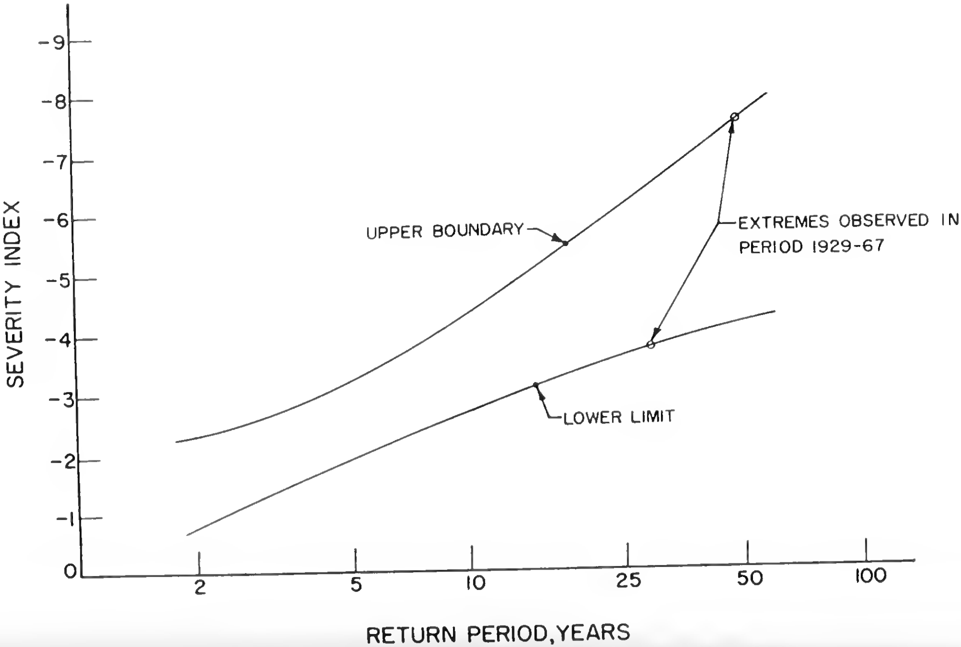


Figure 2. Frequency relationships for drought severity-Central climatological division of Massachusetts (19-02).


SEVERITY INDEX
RETURN PERIOD, YEARS
UPPER BOUNDARY
LOWER LIMIT
EXTREMES OBSERVED IN PERIOD 1929-67
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
2
5
10
25
50
100

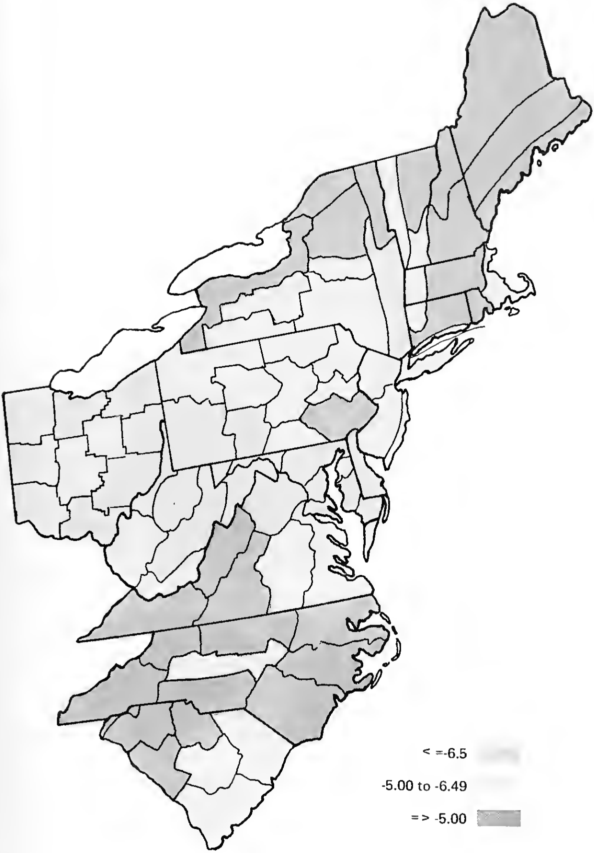


Figure 4. Greatest drought severity for period 1929-67.

TABLE 2. DROUGHT SEVERITY INDICES*

Location		Return Period Values					Extreme
State	Division	2 Yr.	5 Yr.	10 Yr.	25 Yr.	50 Yr.	observed
Connecticut (06)	Northwest (01)	-1.05	-2.37	-3.37	-4.67	-5.68	-5.44
	Central (02)	-1.30	-2.43	-3.28	-4.41	-5.26	-4.61
	Coastal (03)	-1.36	-2.62	-3.58	-4.84	-5.80	-5.67
Delaware (07)	North (01)	-1.04	-2.77	-4.07	-5.80	-7.10	-6.54
	South (02)	-0.87	-2.72	-4.11	-5.95	-7.35	-6.66
Maine (17)	North (01)	-1.31	-2.37	-3.17	-4.22	-5.02	-4.49
	South Interior (02)	-1.23	-2.35	-3.20	-4.32	-5.17	-4.27
	Coastal (03)	-1.34	-2.58	-3.52	-4.77	-5.72	-4.95
Maryland (18)	South Eastern Shore (01)	-1.06	-2.66	-3.88	-5.48	-6.69	-7.02
	Central Eastern Shore (02)	-1.17	-2.81	-4.04	-5.67	-6.91	-6.90
	Lower South (03)	-1.30	-2.91	-4.13	-5.74	-6.97	-7.03
	Upper South (04)	-1.21	-2.88	-4.13	-5.79	-7.05	-7.22
	North Eastern Shore (05)	-1.01	-2.86	-4.26	-6.11	-7.51	-6.75
	North Central (06)	-1.24	-2.93	-4.20	-5.89	-7.16	-7.10
	Appalachian Mts. (07)	-1.36	-2.93	-4.12	-5.70	-6.89	-6.44
	Allegheny Plateau (08)	-1.43	-2.81	-3.85	-5.23	-6.27	-5.84
Massachusetts (19)	West (01)	-1.04	-2.67	-3.91	-5.53	-6.77	-6.53
	Central (02)	-1.23	-2.48	-3.42	-4.67	-5.61	-4.78
	Coastal (03)	-1.23	-2.48	-3.42	-4.67	-5.61	-5.09
New Hampshire (27)	North (01)	-1.12	-2.30	-3.20	-4.38	-5.27	-4.23
	South (02)	-1.32	-2.49	-3.38	-4.55	-5.44	-4.66
New Jersey (28)	North (01)	-1.24	-2.49	-3.43	-4.68	-5.62	-5.32
	South (02)	-1.42	-2.80	-3.85	-5.23	-6.28	-6.47
	Coastal (03)	-1.40	-2.62	-3.53	-4.76	-5.68	-5.09

Table 2 con't

New York (30)	West Plateau (01)	-1.22	-2.70	-3.82	-5.30	-6.42	-5.39
	East Plateau (02)	-1.28	-2.65	-3.68	-5.06	-6.09	-5.85
	North Plateau (03)	-1.32	-2.50	-3.40	-5.48	-5.47	-4.13
	Coastal (04)	-1.36	-2.64	-3.60	-4.88	-5.85	-6.22
	Hudson Valley (05)	-1.29	-2.76	-3.87	-5.34	-6.45	-6.81
	Mohawk Valley (06)	-1.56	-2.76	-3.67	-4.87	-5.79	-5.21
	Champlain Valley (07)	-1.45	-2.82	-3.85	-5.21	-6.24	-4.62
	St. Lawrence Valley (08)	-1.28	-2.56	-3.52	-4.80	-5.76	-4.52
	Great Lakes (09)	-1.34	-2.49	-3.36	-4.51	-5.38	-4.51
	Central Lakes (10)	-1.19	-2.57	-3.62	-5.00	-6.05	-5.03
North Carolina (31)	South Mountains (01)	-1.38	-2.17	-2.67	-3.54	-4.13	-3.72
	North Mountains (02)	Not reported					
	North Piedmont (03)	-1.36	-2.48	-3.33	-4.45	-5.30	-4.76
	Central Piedmont (04)	-1.29	-2.40	-3.24	-4.35	-5.20	-5.47
	South Piedmont (05)	-1.33	-2.38	-3.18	-4.23	-5.03	-4.96
	South Coastal Plain (06)	-0.94	-2.07	-2.92	-4.05	-4.90	-4.06
	Central Coastal Plain (07)	-1.13	-2.38	-3.33	-4.59	-5.54	-4.04
	North Coastal Plain (08)	-1.26	-2.26	-3.02	-4.02	-4.78	-4.53
Ohio (33)	Northwest (01)	-0.75	-2.70	-4.17	-6.11	-7.59	-5.87
	North Central (02)	-0.74	-2.71	-4.20	-6.18	-7.67	-6.61
	Northeast (03)	-0.84	-2.39	-3.56	-5.10	-6.27	-6.57
	West Central (04)	-1.08	-2.76	-4.02	-5.69	-6.95	-6.10
	Central (05)	-1.09	-2.91	-4.28	-6.09	-7.46	-6.21
	Central Hills (06)	-1.42	-3.08	-4.34	-5.99	-7.25	-6.12
	Northeast Hills (07)	-0.98	-2.73	-4.05	-5.81	-7.14	-6.60
	Southwest (08)	-1.29	-3.02	-4.32	-6.05	-7.36	-6.03
	South Central (09)	-1.16	-2.91	-4.23	-5.98	-7.31	-6.81
	Southeast (10)	-1.43	-2.93	-4.06	-5.57	-6.70	-7.25

Table 2 con't

Pennsylvania (33)	Pocono Mts. (01)	-1.16	-2.52	-3.54	-4.90	-5.92	-5.70
	East Central Mts. (02)	-1.38	-2.69	-3.68	-4.99	-5.97	-5.23
	Southeast Piedmont (03)	-1.20	-2.57	-3.61	-4.98	-6.01	-4.96
	Lower Susquehanna (04)	-1.29	-2.82	-3.98	-5.52	-6.68	-6.21
	Middle Susquehanna (05)	-1.05	-2.55	-3.68	-5.17	-6.30	-6.42
	Upper Susquehanna (06)	-1.04	-2.48	-3.56	-4.99	-6.08	-5.69
	Central Mountains (07)	-1.34	-2.59	-3.53	-4.78	-5.72	-5.78
	South Central Mountains (08)	-1.55	-3.01	-4.12	-5.58	-6.69	-7.18
	Southwest Plateau (09)	-1.42	-2.83	-3.89	-5.29	-6.35	-6.70
	Northwest Plateau (10)	-1.15	-2.31	-3.19	-4.35	-5.22	-5.93
Rhode Island (37)	Rhode Island (01)	-1.13	-2.36	-3.29	-4.51	-5.44	-4.67
South Carolina (38)	Mountain (01)	not reported					
	Northwest (02)	-1.14	-2.18	-2.97	-4.01	-4.79	-4.58
	North Central (03)	-1.21	-2.28	-3.09	-4.16	-4.97	-4.69
	Northeast (04)	-0.97	-2.25	-3.22	-4.51	-5.48	-5.08
	West Central (05)	-1.20	-2.24	-3.02	-4.06	-4.85	-3.93
	Central (06)	-0.92	-2.14	-3.07	-4.29	-5.21	-5.00
	Southern (07)	-0.75	-2.10	-3.16	-4.53	-5.57	-5.41
Vermont (43)	Northeast (01)	-1.31	-2.42	-3.26	-4.37	-5.21	-4.21
	West (02)	-1.15	-2.54	-3.60	-4.99	-6.04	-5.69
	Southeast (03)	-1.11	-2.39	-3.35	-4.63	-5.60	-5.72
Virginia (44)	Tidewater (01)	-1.02	-2.57	-3.75	-5.30	-6.48	-5.94
	East Piedmont (02)	-1.06	-2.46	-3.53	-4.93	-6.00	-5.13
	West Piedmont (03)	-1.35	-2.56	-3.47	-4.68	-5.59	-4.49
	North (04)	-1.25	-3.90	-4.15	-5.80	-7.05	-7.39
	Central Mts. (05)	-1.26	-2.47	-3.38	-4.59	-5.51	-4.49
	Southwest Mts. (06)	-1.27	-2.65	-3.68	-5.06	-6.09	-4.90
West Virginia (46)	Northwest (01)	-1.16	-2.90	-4.21	-5.95	-7.26	-7.14
	North Central (02)	-1.37	-2.99	-4.22	-5.84	-7.07	-6.96
	Southwest (03)	-1.05	-2.78	-4.08	-5.80	-7.10	-6.22
	Central (04)	-1.43	-3.00	-4.18	-5.75	-6.93	-6.52
	South (05)	-1.29	-2.77	-3.90	-5.38	-6.51	-6.17
	Northeast (06)	-1.32	-3.02	-4.31	-6.02	-7.30	-7.46

*$R^2 \geq 0.90$ for all divisions

lues of the index were not used. Instead the most extreme drought conditions countered were plotted by climatic divisions and are shown in Figure 4.

Areas of least drought severity, as measured by the Palmer Index, include e mountainous portion of southwestern Virginia and the Carolinas, some astal areas of the Carolinas, the area in New York adjacent to the lakes and nerally all of New England which lies to the east of the Connecticut River. eas which have experienced the worst severity included parts of the Hudson lley, the Del-Mar-Va peninsula, eastern Maryland, northern Virginia. rthern West Virginia, along with the extreme southwestern divisions of nnsylvania and the eastern parts of Ohio. Intermediate areas for severity luded some tidewater areas of the Carolinas and Virginia, upper Pennsylvania d lower New York and this category also encompassed New Jersey and the astal division of New York. As might be expected this pattern showed some emblance to the normal annual rainfall but the correspondence is not very king except that the least severe droughts were associated with the highest vations and high rainfall areas of the Southern Appalachians.

With the exception of the coincidence of low severity with the high rainfall as of the mountains of Virginia and the Carolinas, there appears to be no king relationship between drought patterns and the topography or other dily indentifiable meteorological characteristics of the Northeast.

References

1. Carr, John T. Texas droughts–causes, classification and predicition. Texas Wate Development Board, Report 30. 1966.

2. Chow, Ven Te. Handbook of Applied Hydrology. McGraw-Hill Book Company, Nev New York. 1964.

3. Dethier, B. E. Climate of the northeast–precipitation probabilities. Cornell Universit Agricultural Experiment Station Bulletin 1005. 1965.

4. Fieldhouse, D. J. and W. C. Palmer. Climate of the northeast-meteorological an agricultural droughts. University of Delaware Agricultural Experiment Station Bulleti 353. 1965.

5. Havens, A. V. Drought and agriculture. Weatherwise, Vol. 7, No. 3. 1954.

6. Hoyt, J. C. Drought of 1936, with discussion of drought in relation to climate. U.S Geological Survey, Water Supply Paper 830. 1938.

7. Linsely, Ray K., M. A. Kohler and J. L. H. Paulhus. Hydrology for Engineer McGraw-Hill Book Company, New York. 1958.

8. Palmer, W. C. Meteorological drought. Weather Bureau, U.S. Department of Commerc Research Paper No. 45. 1965.

9. Proceedings of the Conference on the Drought in the Northeastern United Stat Jerome Spar, editor. New York University. 1967.

10. Tannehill, Ivan R. Is weather subject to cycles? U.S. Department of Agricultu Water–The Yearbook of Agriculture. 1955.

11. Weather and Climate Modification. National Academy of Sciences–National Resear Council, Vols. I and II. 1966.